The Essentials of Earthquake-proof Construction

By
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FOREWORD

The following brief discussion of earthquake-proof construction has been prepared by H. M. Hadley, District Engineer of the Portland Cement Association, Seattle, Washington. Mr. Hadley is a structural engineer of extensive experience whom the Portland Cement Association sent to Japan to investigate and report upon the effects of the great Tokyo-Yokohama earthquake, and who again this past summer made a thorough investigation of the effects of the Santa Barbara earthquake. This paper embodies in concise form conclusions drawn from these observations. The very widespread occurrence of earthquakes in recent years is indicative of the fact that they may occur anywhere. There is pith in the old saying, "An ounce of prevention is worth a pound of cure".

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EARTHQUAKES consist of irresistable ground movements, both horizontal and vertical, the earthquake vibrations traveling through the ground at a speed of 6 to 8 miles per second. The horizontal movements may occur in any direction. In any particular earthquake the severe horizontal shocks have a general parallelism of direction but frequently vary through a considerable angular range. The horizontal motion is much greater than the vertical, being generally six to ten times greater. The intensity of shocks varies with the distance of the point of observation from the origin of the disturbance, character of the intervening terrain, etc. When earthquakes occur the effect on all structures that rise above the ground is as if they had been gripped at their bases by gigantic forces which whip them forward and back, to and fro, and to a certain extent up and down.

If the period and movement of the earthquake waves have been measured, the equivalent force may be determined from the formula:

$$F = \frac{(4\pi^2)}{g}\ \frac{(a)}{T^2}\ (W)$$

g=the acceleration of gravity
a=the amplitude of the wave: i. e., one-half of the extreme movement. — what unit?
T=period of the wave, in seconds.
W=weight of structure

An earthquake producing a dynamic effect in a horizontal direction equal to $\frac{1}{10}$ of the weight of structures is a severe earthquake, and may be assumed as the typical case for which provision should be made in design.

Since the vertical movements are relatively small, and since structures are designed to resist vertical loads, the vertical earthquake movement produces little, if any, damage. Practically all damage is produced by the horizontal motion.

Earthquake-Resisting Buildings

Horizontal earthquake motion may be successfully resisted by flexible or rigid frame buildings. The flexible type sways, bends, and deforms with the movement of the ground, but properly designed and connected in all its parts sustains no damage. Steel framed mill buildings, covered with galvanized iron, are of the type of buildings particularly well adapted to flexible framing.

Inasmuch as stone, marble, brick, terra cotta, partition block, glass, plaster, and all the commonly used materials entering into the finished building are in nowise flexible, it follows that the rigid type of building—the one which moves bodily as a block or unit with the ground without major deformation of its structural frame—is the type best adapted to all buildings in which the above mentioned secondary materials are incorporated. A perfect structural frame, with everything vertical which the frame sustains shattered and broken, is not satisfactory.

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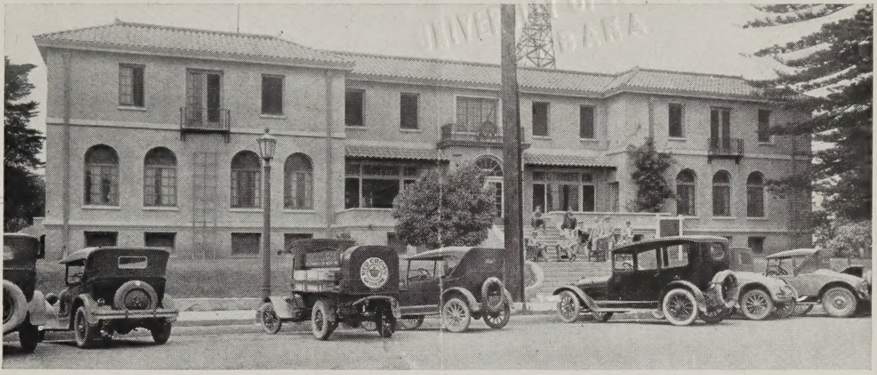
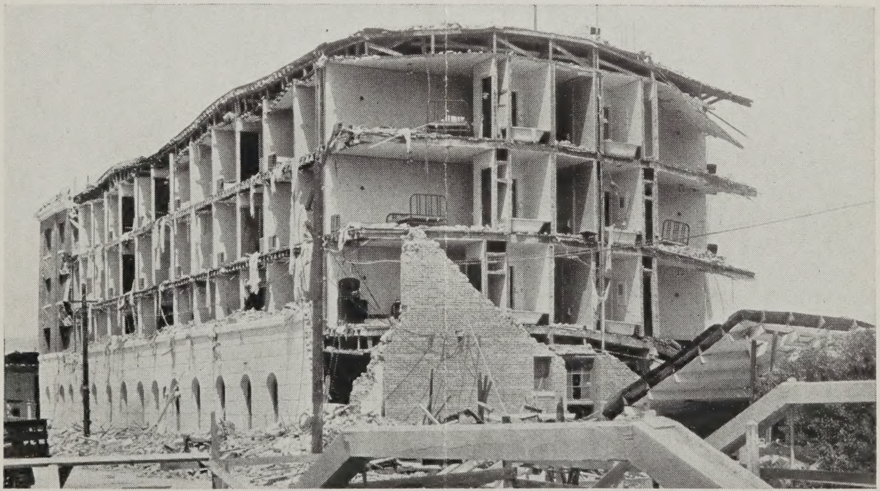


Y. M. C. A. Building, Santa Barbara, California
A well designed brick structure undamaged by earthquake. Exterior is stucco applied directly to brick masonry.

Rigidity of structure may be obtained by vertical trussing, by the wall construction, or by "frame" action: i. e., by bending between girders and columns. However, only the two former methods need be considered, since the third is costly and uneconomical.

Considering the infrequency of severe earthquakes at any one place or location, it is not advisable or to be recommended that elaborate precautions be taken against them. On the other hand, the terrible loss of life and damage to property that may follow their occurrence makes it sheer and utter folly to ignore them. No severe earthquake has ever occurred anywhere that was not a great surprise to the complacent belief that such earthquakes would not occur, or at least were remote and far distant in the future.



Hotel Californian, Santa Barbara, California
The "Ordinary" type of construction suffers great damage in an earthquake due to lack of rigidity of frame and proper ties.

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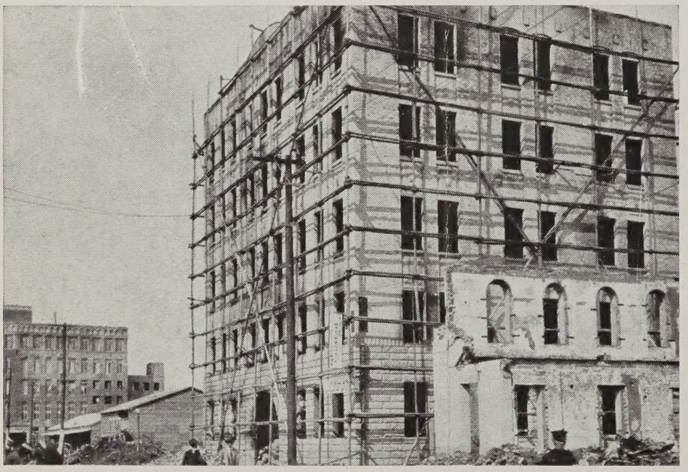
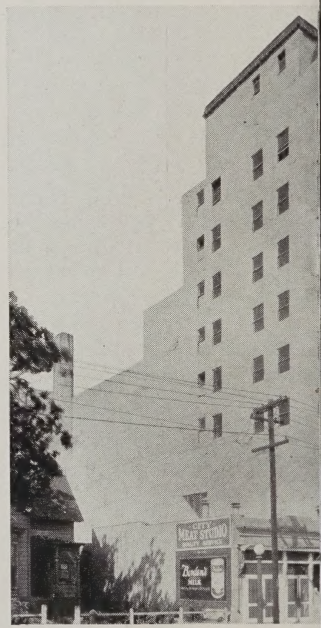
Essence of Earthquake-proof Construction

Foundations should be firm and unyielding at times of earthquakes as at all other times. In soft ground, subject to local fissuring, footings should be so tied and connected together as to maintain them in their normal relative positions. The increased vertical pressures which are applied on the foundations as a result of the horizontal earthquake movements needs particular consideration in the case of structures where the ratio of base width to height of structure is small. Above the ground every structure should be designed in each story to resist horizontal forces acting in any direction. If the usual safety factor of 3 is employed, these horizontal forces may well be regarded as no greater than $\frac{1}{15}$ or $\frac{1}{20}$ of the column and wall loads in that story, since use of and reliance upon reserve strength may well be made in the case of earthquakes whose occurrence at any particular place is fortunately rare and infrequent. While the design against assumed wind loads of various intensities is a somewhat similar precaution, the earthquake force is a function of the combined live and dead loads of the structure whereas wind loads are a function of exposed areas. The two may give widely differing results. The above discussion embodies the essence of earthquake proof construction, to which all else is secondary. Such assumed horizontal forces, acting with a lever arm assumed equal to the story height, must be designed against, and adequate horizontal resistance, computed on precisely the same basis as any other engineering calculation, must be provided. That such adequate horizontal resistance should be properly distributed and not be localized at one particular point or corner of a building is of course obvious.



Menagawa Building, Tokyo, Japan

A reinforced concrete building absolutely undamaged by earthquake. The concrete exterior walls furnished vertical stiffness. Tile veneer was badly spalled by fire and is shown under repair in photograph.



**Granada Building a
Santa Barba**

**Reinforced concrete of rigid t
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also through the wall columns.
failed. While this southeast wal
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Earthquake forces being proportional to the combined live and dead loads, it is manifest that the lighter the dead load, the less will be the earthquake forces. This fact is of no greater significance with respect to horizontal forces, however, than it is with respect to vertical. What is important is designed resistance, whether it be against a force of 1,000,000 lbs. or 1,100,000 lbs.

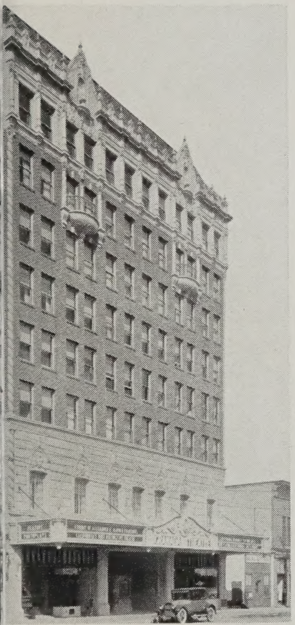
Securing horizontal resistance by vertical trussing needs no discussion. How well it may be incorporated in any building is a problem pertaining to that particular building. It is relatively cheap.

Reinforced Concrete Walls or Partitions

Practically all buildings have walls and partitions of some kind. There is nothing better or cheaper than to make the necessary amount of such wall or partition of reinforced concrete to which the floor systems must be adequately and fully anchored. When the cost of such reinforced concrete wall construction is reduced by the cost of the wall which it replaces, the net increase in cost to transform a building from an earthquake hazard to an earthquake asset will be found to be utterly insignificant.

The reinforced concrete wall is alone recommended because in it alone can reinforcement be introduced to furnish resistance to the tensile stresses which occur simultaneously with compressive stresses. To obtain equivalent results with necessary thicknesses of unreinforced concrete or masonry walls of any other materials of low tensile strength is not economical.

Necessary sections of reinforced concrete wall should be figured as beams, for bending, shear, bond, etc. It will be



Granada Theatre,
California

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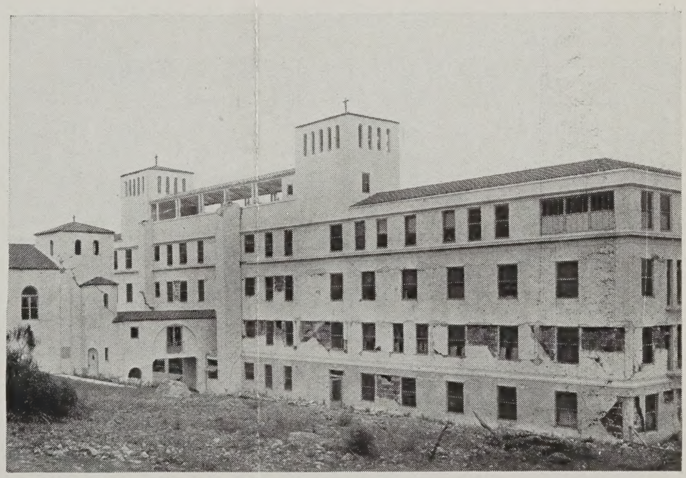
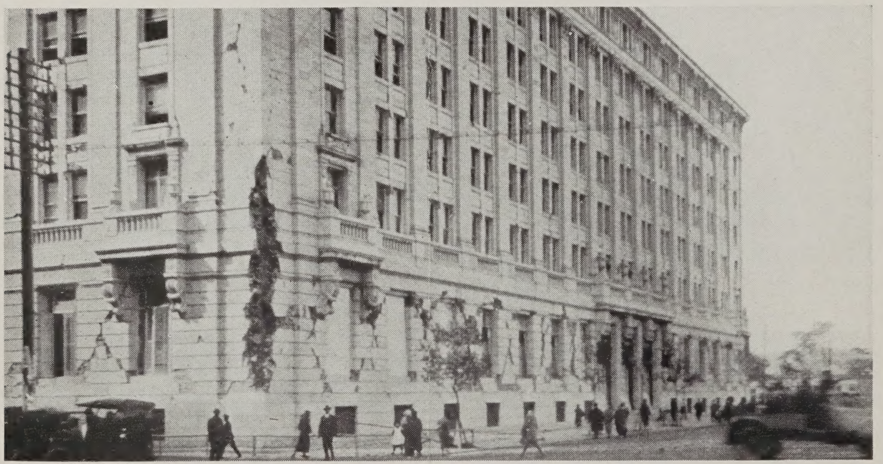


St. Francis Hospital (Rear View) Santa Barbara, California

Reinforced concrete of flexible type with tile filler walls and partitions. The flexibility caused the walls to shatter and spall badly and led to the failure of a number of columns. The very complete destruction of exterior walls and numerous interior partitions created the impression of much greater structural damage than actually existed.

Industrial Bank of Japan, Tokyo, Japan
Steel framed building undamaged by earthquake. Reliance for stiffening was placed on the interior reinforced concrete walls.

found in general that shear is the controlling factor in determining thicknesses. Prof. W. A. Slater's shear tests conducted for the Concrete Ship Section, Emergency Fleet Corporation, are summarized in an article in the Engineering News-Record February 27, 1919, and are soon to be published in detail. In deep beams in which the web reinforcement and main longitu-



Nippon Yusen Kaisha Building, Tokyo, Japan
Although built with exceptionally heavy steel frame and unusual care in details, the elasticity of the frame in conjunction with the use of brick and hollow tile for exterior walls and interior partitions caused exceedingly heavy damage.

dinal reinforcement was fully and adequately anchored ultimate shearing stresses of from 1300 lbs. per square inch to 2500 lbs. per square inch were obtained with concrete of an average ultimate compressive strength of 5200 lbs. per square inch. In wall construction, similarly proportioned and disposed reinforcement may well be expected to develop an ultimate shearing unit strength of 500 lbs. per square inch to 1000 lbs. per square inch with a 2000-lb. concrete. A working stress of one-third of these values may well be employed.

If a proper amount of well distributed resistance has been provided by trussing or reinforced concrete wall section, then the remainder of the wall construction may be made of the filler type with any of the commonly used materials. The structural wall will naturally reduce in thickness and amount of reinforcement from the first story upwards. A somewhat similar reduction may likewise well be made in the filler wall thicknesses.

It follows from the above that skeleton construction carried to the extreme limits not infrequent in present American practice is not recommended. Ordinary skeleton construction with all materials is lacking in resistance to earthquake forces. Neither can reliance be placed on filler wall material to supply the deficiencies of the structural parts. Damage, up to complete collapse, may be expected from it.

All Structures Should Be An Integral Whole

With all materials every effort should be made to so tie and interconnect all parts that the resultant structure is an integral whole. In reinforced concrete construction the following points deserve consideration.

Particular care should be given to securing clean, well made construction joints free from laitance, sawdust, shiplap, or refuse.

In vertical rodded columns, binders should be closely spaced for some distance at both top and bottom. Any deflection of one end with respect to the other induces bending stresses in the column which are a maximum at the ends, and consequently it is at the ends that the need for additional binders is apparent.

All reinforcement should be adequately and fully anchored. The practice ot embedding slab, beam and girder reinforcement only a few inches into supports is criminal.

The only points at which floor systems seem likely to show any signs of distress are at the main corners of the building. Here diagonal cracks at an angle of approximately 45° with the side walls sometimes occur, at any distance up to 8 or 10 feet from the corner column. Diagonal bands of reinforcement running well back into the floor slab are consequently advisable at these points. In skeleton framed buildings damage to the stair framing may be expected.

In L or U shaped buildings, the reentrant corners require particular consideration, as the junction points of sections of building with different periods of vibration. Similarly, where portions of a building are of different height, the junction of such portions, particularly at the roof line of the lower portion, will be severely stressed.

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In reinforced concrete filler walls, the corners of window openings are points of weakness. Either diagonal bars at these corners or additional adequately anchored vertical and horizontal reinforcement on all sides of the opening are recommended.

Following a severe earthquake, there is every probability that fires will break out and should such fires get out of control, the resulting conflagrations will do damage far in excess of the earthquake. San Francisco, Tokyo, Yokohama have all borne testimony to this fact. Fireproof construction, not only in respect to the frames of buildings but also in respect to all windows, doors, and other openings then justifies itself again. The best insurance which a structure may have against both earthquake and fire is that which is built into it.

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